NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

FACILITY FORM 602
N65-24976 (ACCESSION NUMBER) (THRU)
5 (PAGES) 1 (CODE)
TMX-56492 (NASA CR OR TMX OR AD NUMBER) 02 (CATEGORY)

GPO PRICE $
OTS PRICE(S) $
Hard copy (HC) 1.00
Microfiche (MF) .50

Materials for the Mach 3 Supersonic Transport

by

George C. Deutsch
Chief, Materials Research Program
Office of Advanced Research and Technology

Presented at the Materials Division
American Ordnance Association

Dayton, Ohio, September 23-25, 1964

The program that I will present has been a joint effort of the NASA, the Air Force, and the FAA. It is a little awkward to discuss the Mach 3 supersonic transport at this time because it seems to me that everytime I pick-up a technical magazine they are having a special issue devoted to this airplane. Even such publications at Time, Newsweek, the Washington Post, and the New York Times have lately carried lengthy articles about this airplane. This, of course, means that what I am about to say is hardly novel. However, I hope to add some new ideas or perhaps some greater detail to what may have been said before.

It may be well to dwell for a minute on the reasons why this airplane has received so much publicity. These are shown in my first figure. The first item is that the Mach 3 Supersonic Transport represents a major advance in aircraft technology. In one step this airplane will more than triple the speed of our present highly developed commercial transports. This is, I believe, an exciting possibility to contemplate. The second reason is that the airplane is the object of much international competition. When I read about the international competition in the Wall Street Journal, they point out that the sales of this airplane can make as much as nine billion dollars difference in the gold flow to or from the United States. Incidentally, to date the foreign and domestic airlines have placed $100,000 deposites for 91 of these aircrafts. Other publications stress the importance of this airplane as a prestige item to clearly establish the United States as pre-eminent in technology. The final item is the high cost of this airplane. Each aircraft is estimated to cost well in excess of 20 million dollars--and to achieve the first one requires a development program that costs between five hundred million and one billion dollars. It is, therefore, natural that this airplane would arouse much comment. I will discuss each of these items in somewhat greater detail as

TMX# 56492

I go along. However, before doing so, I would like to refresh your memory about what the airplane looks like.

Figure 2 is an artist's conception of what this airplane might look like. Many versions have appeared in print, and this picture is an arbitrarily selected one. It is introduced to indicate not what we believe is the preferred configuration but to serve as a useful guide on which to base the discussion. The temperatures that will exist in the various parts of the fuselage when the airplane is flying at a speed three times the velocity of sound, about 2,000 miles per hour, are shown. It can be seen that the nose of the airplane and the leading edges of the wings and tail operate at temperatures as high as 600°F, and the rest of the fuselage is 450°F or higher. The hottest parts of the airplane are near the engine exhausts and nacelles where temperatures range as high as 1200°F.

Figure 3 lists the goals for the performance for this airplane. It is hoped that by about 1970 a preliminary version will be available that will perform satisfactorily at a speed of Mach 2.3. It should carry about 150 passengers, and it will be propelled by four turbojet engines of types that exist today. A short time later this same airplane fuselage is to be upgraded to a speed of Mach 3 by installing four engines of types that are currently under development. By 1975 we would like to make another change in the same fuselage and upgrade its speed to about 3.5 by installing six turbojet engines that are currently in their initial phases of development. I have tried to stress that the aircraft structure that we want to build originally should perform satisfactorily over the entire range of conditions shown in the figure. In addition to the specifications in the chart, the airlines have stated that for this plane to be commercially attractive it should have a life of at least 10 years of which 30 to 50,000 hours are to be at rated speed. It is this last feature that of having a long lifetime that differentiates this airplane from the A-11 and the XRB-70. If you stop to think about the numbers in the chart you come up with the very exciting concept of an airplane that will make four transatlantic crossings per day, day after day.

To attain an airplane that will do this job, one can hypothesize with assurance that all the materials for the supersonic transport will present problems. Such items as tires, glazing materials, radomes, and hydraulic fluids and systems all have to be improved before they will perform satisfactorily. However, the bulk of the effort to date has gone into the study of the skin and fuselage materials and it is in this area that I will principally comment.

Figure 4 shows the effect of aircraft speed on the temperature of the aircraft structure. We can see that at the point at which present airlines operate today--just below Mach 1 --there is very little change in temperature; however, above this speed the temperature rises very rapidly so at Mach 3 it is slightly in excess of 500°. Also shown in the figure is the strength of various materials as a percentage of their room temperature strengths. The lowest curve is 2219, a structural aluminum alloy. We can see that in the vicinity in which we are interested, between Mach 2 and 3 the strength of this alloy falls off very rapidly. The titanium alloy, 6-4, also decreases in strength as does the preciptation hardening steel, AM 355, but not so precipitously as does the aluminum alloy. The best alloy is the nickel alloy, INCO 718 which is degraded only slightly by the temperature. On the basis of this figure one can eliminate the aluminum alloy. The remaining alloys must then be considered in greater detail.

Figure 5 lists the properties that are required to make further selections. These properties include the conventional strength, forming, and joining parameters that are considered for every airplane. However, because of the high operating temperature we are also forced to consider the metallurgical stability of the alloy. The metallurgical stability is the ability of the alloy to resist such processes as relaxation and aging, and to retain its strength and toughness for the desired life time. On the basis of such a list it would appear that the selection might be quite easy and it is only necessary to turn to standard handbooks. This is not at all the case. The use temperatures are outside the range for which these alloys are normally considered and the life times are beyond those used in design. Therefore, most of the work accomplished to date has been to accumulate the data required for selection purposes.

Figure 6 lists the alloys that were considered. Our initial job was to survey these alloys to obtain the properties I showed on the previous figure. The list contains titaniums, superalloys, and both preciptation hardening and austenitic stainless steels. The titaniums included alpha and the alpha-beta alloys with particular emphasis on the alpha. A representative selection of iron, nickel, and cobalt-base superalloys were also included. The list of alloys contained 24 candidate materials and when one considers the fact that several were considered in more than one condition of heat treatment it becomes apparent that the selection task is indeed formidable.

Figure 7 shows some of the results. The data is presented on a strength-to-weight ratio basis to simplify comparisons. A most interesting feature of the figure is that the titanium has proved to be the most promising material. The reason is, of course, the low density of titanium. The two verticle shaded bars indicate where the British-French Concorde and the United States airplane fall. We can see that the Concorde has been selected to operate at a range just below that at which the properties of aluminum decreases. This figure also illustrates the fact that the Concorde doesn't have the growth potential that we hope to incorporate in our airplane. For example, the United States' airplane was set to operate on the flat part of the curves, at temperatures reasonably below that at which the steel and titanium lose their strength.

Many newspaper accounts of this airplane suggest that we are also competing with the Russians; although, I have seen no definitive material on Russia's airplane, a good guess is that one of the materials that the Russians are looking at is dispersion hardened aluminum alloy for the structure of the aircraft. This will put them in a temperature range with the United States rather than the Concorde.

Earlier I talked about the large volume of data that is being obtained. Some of this is illustrated in the Figure 8. This data was obtained with specimens that have been suspended in a furnace for very long periods of time. The chage of strength that may have taken place is measured. We can see that now data for as long as 22,000 hours are available and that the data looks very good. No significant changes in strength can be detected with titanium or the preciptation hardened stainless steels. On the other hand, the austenitic steels that were strengthened by severe cold working have deteriorated badly. It is only since significant quantities of such data and parallel data obtained from loaded specimens are available that we feel confident in our ability to build a plane having the desired life.

One important consideration that the materials must have is the ability to withstand the presence of cracks. This ability is shown in Figure 9 for the three temperatures of interest to the airplane. The low temperature (-109°F) is the ambient temperature at the cruise altitude, room temperature the temperature at which the airplane will take off, and 550°F the normal operating temperature for the structure. As in the proceeding figure, the strength has been divided by the density to permit comparisons between alloys. The shaded bars give the smooth specimen strength and the solid black bars the strength in the presence of a one inch crack in the eight inch wide specimen. The 8-1-1 titanium, in the triplix annealed condition is superior on the basis of tensile and notch strength at every temperature except 550°F, where the same alloy in the annealed condition excelled. The design people like the type of numbers shown in this figure. The titanium is relatively insensitive to cracking and they point out that this amount of decrease is less weakening then is present in the aluminum alloys in some of our present subsonic commercial transports.

Figure 10 also deals with the ability of a material to keep operating in the presence of cracks. On this figure we have plotted the rate at which a crack will grow under cyclic loading conditions. The figure contains an aluminum, a stainless steel, and a titanium alloy. It can be seen that the rate at which the crack grows is lowest for the titanium alloy - but to me the most surprising feature of the figure is that the rate is considerably lower than for the 2024 aluminum--an alloy we consider to be of the "fail-safe" variety.

Thus far we have considered what are candidate materials for the structure of supersonic transport and how do they stack up with each other. One other factor to be considered is corrosion resistance. The supersonic transport is expected to operate primarily from airports in the vicinity of the oceans and spend much of its flying time over these oceans. It appears very likely it will frequently encounter sea salt. It is of course essential that it be able to resist the corrosive effect of this salt. Figure 11 shows the behavior of titanium in the presence of sea salt as a function of the stress and exposure time. This figure was prepared from a compilation of all published data available to date and is at 650°F. It can be seen that at a stress of about 20,000 psi the titanium alloy is resistant to stress corrosion cracking for very long times. It can also be seen that above a stress of about 100,000 psi fracture occurs in a very short time. At intermediate stresses the behavior is intermediate. It should be recalled that this figure is for results at 650°F - a temperature in excess of that which will be encountered by the airplane. Unfortunately, at the Mach 3 operating temperature the data is not yet definitive. Many people, however, feel that there is a threshold for corrosion and it is above the temperatures which the airframe will see at a speed of Mach 3. The temperature (650°F) shown in the figure will, however, be encountered in the compresser vanes and disk; and overhaul and inspection procedures will have to take this into account.

Some data at 550° is shown in Figure 12. In this test, specimens that are bowed to induce stress are held at 550° for up to three thousand hours after being lightly coated with salt. After exposure these specimens are compressed and if cracking has occurred the specimen will fracture rather than bend. The upper curve shows then effect of compression for a blank exposed to temperature without salt. The lower curves shows the very serious effect of salt. At the present time the situation with regards to stress corrosion is rather confused. Essentially the engineers feel that the situation is comparable to that which has existed many times before during preliminary planning of the aircraft and they feel that, as in the past, solutions will be forthcoming. The metallurgist tends to be more cautious.

To summarize, I have tried to present some of the metallurgical problems that have been encountered with the structure of the Mach 3 supersonic transport and some of the progress that has been made towards solving these problems. As was stated earlier, to date most attention has been placed on the aircraft skin, however, programs on materials for thick sections components, the engines, and other parts are moving rapidly along.

- END -